



A Neutrosophic Interpretation of the Island Rule: From the Tethys Ocean to Urban Gigantism in Freshwater Crabs

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Abstract: This paper proposes an extension of the Neutrosophic Theory of Evolution into the field of evolutionary biogeography. Using the freshwater crab *Potamon fluviatile* as a case study, we analyze how evolutionary, involutionary, and indeterminate processes interact across geological, ecological, and spatial scales. The species originated from marine ancestors in the ancient Tethys Ocean and later colonized freshwater ecosystems across the Mediterranean basin. A long-isolated population inhabiting subterranean canals beneath the ruins of Rome exhibits unusual body size and longevity, suggesting a form of island-like gigantism. We argue that such evolutionary phenomena can be interpreted within a neutrosophic framework where adaptation involves simultaneous processes of evolution, involution, and indeterminacy. This study represents the first formal applications of neutrosophic theory to evolutionary biogeography.

Keywords: neutrosophic evolution, evolutionary biogeography, island rule, *Potamon fluviatile*, Tethys Ocean, freshwater crab evolution, ecological isolation, gigantism, subterranean ecosystems, urban evolutionary habitats.

1. Introduction

The introduction should briefly place the study in a broad context and highlight why it is important. It should define the purpose of the work and its significance. The current state of the research field should be reviewed carefully and key publications cited. Please highlight controversial and diverging hypotheses when necessary. Finally, briefly mention the main aim of the work and highlight the principal conclusions. As far as possible, please keep the introduction comprehensible to scientists outside your particular field of research. References should be numbered in order of appearance and indicated by a numeral or numerals in square brackets, e.g., [1] or [2,3], or [4–6]. See the end of the document for further details on references.

Evolutionary biology traditionally interprets adaptation as a directional process driven by natural selection. However, many biological systems display patterns that cannot be easily described as purely progressive change.

The **Neutrosophic Theory of Evolution** (Smarandache 2017a) proposes that every adaptive process involves three simultaneous components:

- **Evolution** – development of advantageous traits;
- **Involution** – degeneration or loss of traits;
- **Indeterminacy (neutrality)** – traits that remain unchanged or whose change is ambiguous.

The conceptual motivation for applying this framework to evolutionary biogeography derives from an observation described in a recent natural-history report about freshwater crabs living beneath Roman ruins (BBC Wildlife / Discover Wildlife, 2026).

An isolated colony of **Potamon fluviatile** inhabits underground waterways in the ruins of Trajan's Markets in Rome. These crabs have persisted there for centuries and individuals grow larger than typical members of the species, reaching around **7 cm compared to the usual 5 cm**, which researchers interpret as a case of **isolated population gigantism**.

The population likely became isolated when Roman engineering projects altered the hydrology of the area and disconnected the canals from the **Tiber River**, trapping the crabs within subterranean drainage systems.

This phenomenon raises an important theoretical question:

Can patterns of evolutionary isolation such as the island rule be interpreted through neutrosophic evolutionary dynamics?

2. The Island Rule

Body size evolution in isolated ecosystems often follows a pattern known as the *island rule*, according to which small species tend to evolve gigantism while large species tend to evolve dwarfism (Foster, 1964; Lomolino, 2005).

Recent large-scale analyses confirm that the island rule explains consistent patterns of body size evolution in terrestrial vertebrates (Benítez-López et al., 2021).

Ecological isolation plays a fundamental role in shaping evolutionary trajectories, as predicted by the theory of island biogeography (Whittaker & Fernández-Palacios, 2007).

Isolation alters ecological pressures such as: predation, competition, food availability, or dispersal opportunities. These changes influence life-history strategies and morphological evolution. Examples include: dwarf elephants of Mediterranean islands, giant reptiles on isolated islands, unusual size variation in cave species.

The Roman freshwater crab population represents **a similar phenomenon occurring within an urban subterranean ecosystem**.

3. Geological Origins: The Tethys Ocean

Freshwater crabs of the Mediterranean region belong to ancient brachyuran lineages that likely originated from marine ancestors inhabiting the Tethys Ocean (Ng et al., 2008).

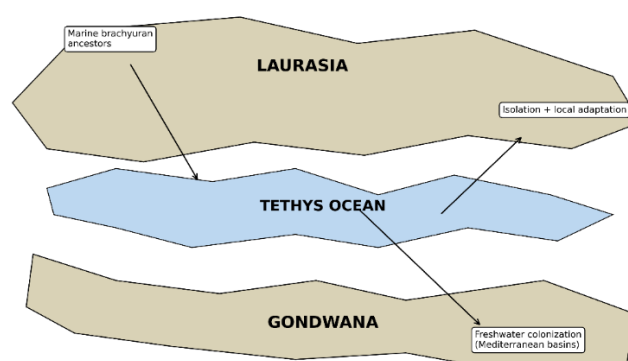


Figure 1. Conceptual paleobiogeographic diagram showing the transition from marine brachyuran ancestors in the Tethys Ocean to freshwater colonization and later isolation in Mediterranean habitats.

During the Mesozoic and early Cenozoic eras, tectonic processes fragmented this ocean, producing the Mediterranean basin and several inland seas.

As coastlines shifted, populations of marine crabs gradually colonized estuaries, coastal wetlands, and river systems.

This transition required physiological innovations such as:

- **osmoregulation** in freshwater,
- **direct embryonic** development.

Today the species inhabits rivers and streams across southern Europe and parts of the Balkans.

4. Freshwater Adaptation

Freshwater crabs of the Mediterranean region belong to ancient brachyuran lineages that likely originated from marine ancestors inhabiting the Tethys Ocean (Ng et al., 2008).

Unlike marine crabs, freshwater species such as **Potamon fluviatile** exhibit direct development: embryos develop inside eggs carried by females, and juvenile crabs emerge fully formed without a planktonic larval stage.

This adaptation enables survival in isolated freshwater habitats but simultaneously limits dispersal.

Consequently: populations become geographically fragmented, genetic divergence increases, local ecological specialization may occur.

This dual outcome illustrates the neutrosophic coexistence of evolutionary innovation and evolutionary constraint.

5. Urban Subterranean Isolation

A remarkable population of **Potamon fluviatile** inhabits underground canals connected to the **Cloaca Maxima**, Rome’s ancient drainage system. Researchers believe that urbanization isolated this population centuries ago, effectively creating a **biological island** within the city.

The population of freshwater crabs living beneath Roman ruins shows unusual body size and longevity, suggesting a form of ecological gigantism associated with isolation (BBC Wildlife / Discover Wildlife, 2026; Palomba, 2024).

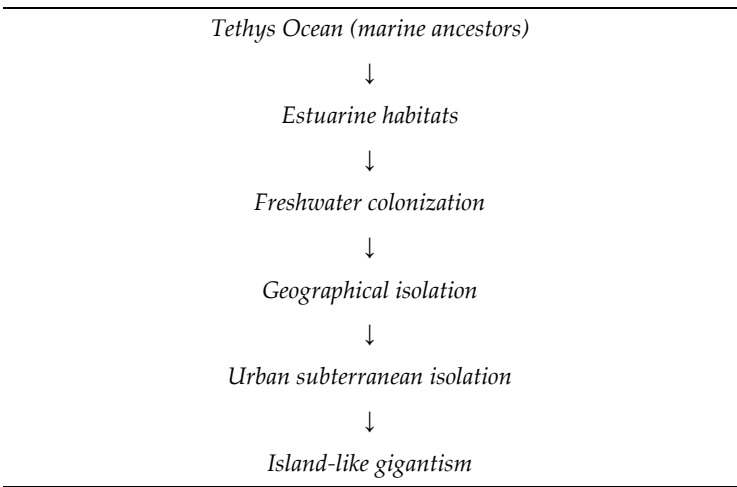
Individuals in this environment display unusual traits: larger body size, longer lifespan, strong adaptation to subterranean habitats.

Some specimens may reach sizes significantly larger than typical populations, and isolated populations can show increased longevity up to **15 years**.

6. Conceptual Evolutionary Pathway

The evolutionary trajectory of the species can be summarized as follows:

Diagram 1. Conceptual evolutionary pathway illustrating the transition of *Potamon fluviatile* from marine ancestors in the Tethys Ocean to isolated freshwater populations. The sequence shows successive ecological stages—marine origin, estuarine transition, freshwater colonization, geographic isolation, and urban subterranean confinement—culminating in island-like gigantism. Each stage represents the influence of new environmental pressures that shape adaptive responses over evolutionary time.



Each stage introduces new ecological pressures and adaptive responses.

7. The Neutrosophic Triangle of Evolution

According to the **Neutrosophic Theory of Evolution**, adaptive processes involve simultaneous degrees of evolution, involution, and indeterminacy (Smarandache, 2017a).

This framework suggests that evolutionary phenomena such as the island rule may reflect multidimensional adaptive equilibria rather than purely directional evolutionary change (Smarandache, 2017a; Mao, 2016).

Adaptive states can be represented as a **neutrosophic triangle**:

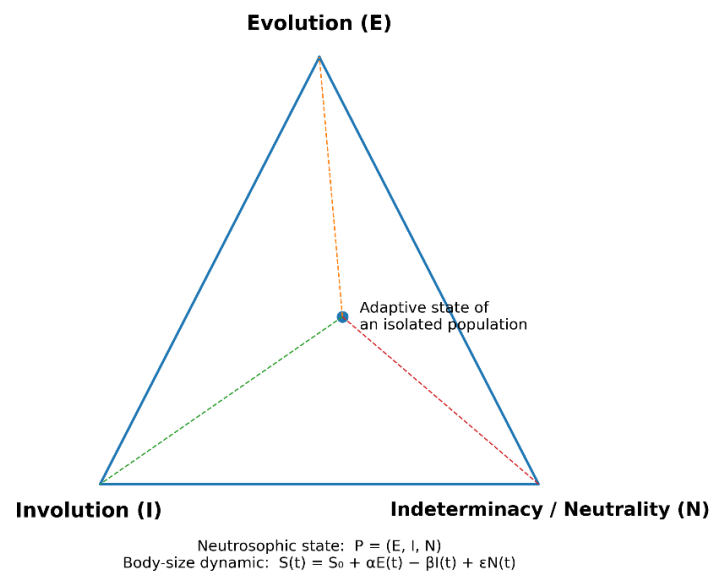


Figure 2. Neutrosophic triangle of adaptive change, illustrating the dynamic balance between Evolution (E), Involution (I), and Indeterminacy/Neutrality (N) in isolated populations.

An organism's position within this triangle changes according to environmental conditions. For isolated populations:

- E increases through adaptation,
- I increases through loss of unused traits,
- N represents conserved ancestral traits.

8. Comparative Evidence from the Island Rule

Several evolutionary phenomena illustrate similar dynamics:

Table 1. Examples of evolutionary responses to ecological isolation illustrating the dynamics of the island rule across different environments. Isolated habitats—such as islands, caves, and urban subterranean systems—can produce diverse adaptive outcomes including dwarfism, gigantism, and morphological change, reflecting the complex balance between evolutionary innovation, involutionary constraints, and environmental pressures.

Example	Isolation Type	Outcome
Mediterranean dwarf elephants	islands	dwarfism
Komodo dragon relatives	islands	gigantism
cave salamanders	subterranean	morphological change
Roman freshwater crabs	urban subterranean	gigantism

These cases demonstrate that isolation produces complex adaptive responses rather than simple directional evolution.

9. Neutrosophic Mathematical Model

Let a biological population be described by three neutrosophic parameters:

$$P = (E, I, N)$$

where:

- E = evolutionary change
- I = involutionary regression
- N = neutral persistence.

Trait variation (e.g., body size) may be modeled as:

$$S(t) = S_0 + \alpha E(t) - \beta I(t) + \epsilon N(t)$$

where:

- S_0 = ancestral size
- α = evolutionary growth coefficient
- β = involutionary constraint
- ϵ = neutral fluctuation.

Gigantism emerges when:

$$\alpha E > \beta I$$

while **dwarfism** emerges when:

$$\beta I > \alpha E$$

Thus the island rule can be interpreted as a **neutrosophic balance between evolutionary expansion and involutionary constraint**.

10. Evolutionary Biogeography as a Neutrosophic System

The evolutionary history of **Potamon fluviatile** illustrates a sequence of neutrosophic states:

Table 2. Conceptual neutrosophic framework for the evolutionary history of *Potamon fluviatile*, integrating geological context, habitat transitions, and evolutionary dynamics.

Stage	Environment	Dominant process
Marine ancestor	Tethys Ocean	evolution
Estuarine transition	coastal habitats	indeterminacy
Freshwater colonization	rivers	evolution + involution
Habitat fragmentation	Mediterranean basins	isolation
Roman subterranean ecosystem	urban habitat	gigantism

This interpretation links geology, ecology, and evolutionary dynamics.

11. Implications

The neutrosophic framework suggests new interpretations for several evolutionary phenomena:

- island rule,
- cave gigantism,
- adaptive radiation,
- evolutionary stasis.

Rather than representing purely directional evolution, these phenomena may reflect **multidimensional adaptive equilibria**.

The proposed model is conceptual and intended primarily as a theoretical framework rather than a predictive evolutionary model.

12. Conclusion

The evolutionary trajectory of the freshwater crab **Potamon fluviatile**, from marine ancestors in the Tethys Ocean to isolated populations beneath the ruins of Rome, illustrates the complex dynamics of adaptation in isolated environments. The unusual body size observed in Roman populations resembles the island rule and can be interpreted through the **Neutrosophic Theory of Evolution**, where adaptation involves simultaneous processes of evolution, involution, and neutrality. This work therefore represents **one of the first formal attempts to apply neutrosophic theory to evolutionary biogeography**, offering a conceptual bridge between logic, ecology, and evolutionary theory.

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